

Claims

1. A method of monitoring a reverse osmosis membrane separation process including a reverse osmosis membrane capable of separating a feed stream into at least a first stream and a second stream comprising the steps of:
 - 5 providing an inert fluorescent tracer;
 - introducing the inert fluorescent tracer into the feed stream;
 - providing a fluorometer to detect the fluorescent signal of the inert fluorescent tracer in at least one of the feed stream, the first stream and the second stream; and
 - using the fluorometer to determine an amount of the inert fluorescent tracer in at least one of the feed stream, the first stream and the second stream.
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15 2. The method of claim 1 further comprising the step of evaluating a process parameter of the reverse osmosis membrane separation process based on the amount of the inert fluorescent tracer that is measured.
3. The method of claim 1 wherein the reverse osmosis membrane separation process is selected from the group consisting of a cross-flow reverse osmosis membrane separation process and a dead-end flow reverse osmosis membrane separation process.
- 20 4. The method of claim 1 wherein the inert fluorescent tracer is selected from the group consisting of 3,6-acridinediamine, N,N,N',N'-tetramethyl-,monohydrochloride; 2-anthracenesulfonic acid sodium salt; 1,5-anthracedisulfonic acid; 2,6-anthracedisulfonic acid; 1,8-anthracedisulfonic acid; anthra[9,1,2-cde]benzo[rst]pentaphene-5,10-diol, 16,17-

dimethoxy-,bis(hydrogen sulfate), disodium salt; bathophenanthrolinedisulfonic acid disodium salt; amino 2,5-benzene disulfonic acid; 2-(4-aminophenyl)-6-methylbenzothiazole; 1H-benz[de]isoquinoline-5-sulfonic acid, 6-amino-2,3-dihydro-2-(4-methylphenyl)-1,3-dioxo-, monosodium salt; phenoxazin-5-i um, 1-(aminocarbonyl)-7-(diethylamino)-3,4-dihydroxy-,
5 chloride; benzo[a]phenoxazin-7-i um, 5,9-diamino-,acetate; 4-dibenzofuransulfonic acid; 3-dibenzofuransulfonic acid; 1-ethylquinaldinium iodide; fluorescein; fluorescein, sodium salt; Keyfluor White ST; benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-[4-[bis(2-hydroxyethyl)amino]-6-[(4-sulfophenyl)amino]-1,3,5-triazin-2-yl]amino]-,tetrasodium salt; C.I. Fluorescent Brightener 230; benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-[4-[bis(2-hydroxyethyl)amino]-6-[(4-sulfophenyl)amino]-1,3,5-triazin-2-yl]amino]-,tetrasodium salt; 9,9'-biacridinium, 10,10'-dimethyl-, dinitrate; 1-deoxy-1-(3,4-dihydro-7,8-dimethyl-2,4-dioxobenzo[g]pteridin-10(2H)-yl)- ribitol; mono-, di-, or tri-sulfonated naphthalenes selected from the group consisting of 1,5-naphthalenedisulfonic acid, disodium salt (hydrate); 2-amino-1-naphthalenesulfonic acid; 5-amino-2-naphthalenesulfonic acid; 4-amino-3-hydroxy-1-naphthalenesulfonic acid; 6-amino-4-hydroxy-2-naphthalenesulfonic acid; 7-amino-1,3-naphthalenesulfonic acid, potassium salt; 4-amino-5-hydroxy-2,7-naphthalenedisulfonic acid; 5-dimethylamino-1-naphthalenesulfonic acid; 1-amino-4-naphthalene sulfonic acid; 1-amino-7-naphthalene sulfonic acid; and 2,6-naphthalenedicarboxylic acid, dipotassium salt; 3,4,9,10-perylenetetracarboxylic acid; C.I. Fluorescent Brightener 191; C.I. Fluorescent Brightener 200;
10 benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-(4-phenyl-2H-1,2,3-triazol-2-yl)-, dipotassium salt; benzenesulfonic acid, 5-(2H-naphtho[1,2-d]triazol-2-yl)-2(2-phenylethenyl)-, sodium salt; 1,3,6,8-pyrenetetrasulfonic acid, tetrasodium salt; pyranine; quinoline; 3H-phenoxyazin-3-one, 7-hydroxy-, 10-oxide; xanthylum, 9-(2,4-dicarboxyphenyl)-3,6-bis(diethylamino)-, chloride,
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disodium salt; phenazinium, 3,7-diamino-2,8-dimethyl-5-phenyl-, chloride; C.I. Fluorescent Brightener 235; benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-[4-[bis(2-hydroxyethyl)amino]-6-[(4-sulfophenyl)amino]-1,3,5-triazin-2-yl]amino]-, tetrasodium salt; benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-[4-[(2-hydroxypropyl)amino]-6-
5 (phenylamino)-1,3,5-triazin-2-yl]amino]-, disodium salt; xanthylum, 3,6-bis(diethylamino)-9-(2,4-disulfophenyl)-, inner salt, sodium salt; benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-[4-[(aminomethyl)(2-hydroxyethyl)amino]-6-(phenylamino)-1,3,5-triazin-2-yl]amino]-, disodium salt; Tinopol DCS; benzenesulfonic acid, 2,2'-(1,1'-biphenyl)-4,4'-diyldi-2,1-ethenediyl)bis, disodium salt; benzenesulfonic acid, 5-(2H-naphtho[1,2-d]triazol-2-yl)-2-(2-phenylethenyl)-,
10 sodium salt; 7-benzothiazolesulfonic acid, 2,2'-(1-triazene-1,3-diyldi-4,1-phenylene)bis[6-methyl-, disodium salt; and all ammonium, potassium and sodium salts thereof; and all mixtures thereof.

5. The method of claim 1 wherein the inert fluorescent tracer is selected from the
15 group consisting of 1-deoxy-1-(3,4-dihydro-7,8-dimethyl-2,4-dioxobenzo[g]pteridin-10(2H)-yl)-D ribitol; fluorescein; fluorescein, sodium salt; 2-anthracenesulfonic acid sodium salt; 1,5-anthracenedisulfonic acid; 2,6-anthracenedisulfonic acid; 1,8-anthracenedisulfonic acid; mono-, di-, or tri-sulfonated naphthalenes selected from the group consisting of 1,5-naphthalenedisulfonic acid, disodium salt (hydrate); 2-amino-1-naphthalenesulfonic acid; 5-amino-2-naphthalenesulfonic acid; 4-amino-3-hydroxy-1-naphthalenesulfonic acid; 6-amino-4-hydroxy-2-naphthalenesulfonic acid; 7-amino-1,3-naphthalenesulfonic acid, potassium salt; 4-amino-5-hydroxy-2,7-naphthalenedisulfonic acid; 5-dimethylamino-1-naphthalenesulfonic acid; 1-amino-4-naphthalene sulfonic acid; 1-amino-7-naphthalene sulfonic acid; and 2,6-

naphthalenedicarboxylic acid, dipotassium salt; 3,4,9,10-perylenetetracarboxylic acid; C.I. Fluorescent Brightener 191; C.I. Fluorescent Brightener 200; benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-(4-phenyl-2H-1,2,3-triazol-2-yl)-, dipotassium salt; benzenesulfonic acid, 5-(2H-naphtho[1,2-d]triazol-2-yl)-2-(2-phenylethenyl)-, sodium salt; 1,3,6,8-pyrenetetrasulfonic acid, tetrasodium salt; pyranine; quinoline; 3H-phenoxyazin-3-one, 7-hydroxy-, 10-oxide; 5 xanthylum, 9-(2,4-dicarboxyphenyl)-3,6-bis(diethylamino)-, chloride, disodium salt; phenazinium, 3,7-diamino-2,8-dimethyl-5-phenyl-, chloride; C.I. Fluorescent Brightener 235; benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-[[4-[bis(2-hydroxyethyl)amino]-6-[(4-sulfophenyl)amino]-1,3,5-triazin-2-yl]amino]-, tetrasodium salt; benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-[[4-[4-[2-hydroxypropyl]amino]-6-(phenylamino)-1,3,5-triazin-2-yl]amino]-, 10 disodium salt; xanthylum, 3,6-bis(diethylamino)-9-(2-4-disulfophenyl)-, inner salt, sodium salt; benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-[[4-[(aminomethyl)(2-hydroxyethyl)amino]-6-(phenylamino)-1,3,5-triazin-2-yl]amino]-, disodium salt; Tinopol DCS; benzenesulfonic acid, 2,2'-(1,1'-biphenyl)-4,4'-diyldi-2,1-ethenediyl)bis-, disodium salt; benzenesulfonic acid, 5-(2H-naphtho[1,2-d]triazol-2-yl)-2-(2-phenylethenyl)-, sodium salt; 7-benzothiazolesulfonic acid, 2,2'-(1-triazene-1,3-diyldi-4,1-phenylene)bis[6-methyl-, disodium salt; and all ammonium, 15 potassium and sodium salts thereof; and all mixtures thereof.

6. The method of claim 1 wherein the inert fluorescent tracer is selected from the group consisting of 1,3,6,8-pyrenetetrasulfonic acid tetrasodium salt; 1,5-naphthalenedisulfonic acid disodium salt (hydrate); xanthylum, 9-(2,4-dicarboxyphenyl)-3,6-bis(diethylamino)-, 20 chloride, disodium salt; 1-deoxy-1-(3,4-dihydro-7,8-dimethyl-2,4-dioxobenzo[g]pteridin-10(2H)-yl) – D-ribitol; fluorescein; fluorescein, sodium salt; 2-anthracenesulfonic acid sodium

salt; 1,5-anthracenedisulfonic acid; 2,6-anthracenedisulfonic acid; 1,8-anthracenedisulfonic acid; and mixtures thereof.

7. The method of claim 1 wherein the inert fluorescent tracer is introduced into the feed stream in an amount from about 5 ppt to about 1000 ppm.

5 8. The method of claim 1 wherein the inert fluorescent tracer is introduced into the feed stream in an amount from about 1 ppb to about 50 ppm.

9. The method of claim 1 wherein the inert fluorescent tracer is introduced into the feed stream in an amount from about 5 ppb to about 50 ppb.

10. 10. The method of claim 1 wherein the inert fluorescent tracer is added directly as a single component into the feed stream.

11. 11. The method of claim 1 wherein the inert fluorescent tracer is added to a formulation and subsequently added to the feed stream.

12. 12. The method of claim 1 wherein the amount of the inert fluorescent tracer is correlated to the amount of the formulation.

15 13. A method of monitoring a reverse osmosis membrane separation system including a reverse osmosis membrane capable of removing solutes from a feed stream suitable for use in an industrial process comprising the steps of:

adding an inert tracer to the feed stream;

contacting the reverse osmosis membrane with the feed stream;

20 separating the feed stream into a permeate stream and a concentrate stream to remove solutes from the feed stream;

providing a fluorometer to detect the fluorescent signal of the inert tracer in at least one of the feed stream, the permeate stream and the concentrate stream; and

using the fluorometer to measure an amount of the inert tracer in at least one of the feed stream, the permeate stream and the concentrate stream.

14. The method of claim 13 further comprising the step of evaluating the removal of
5 solutes from the feed stream based on the amount of the inert tracer that is measured.

15. The method of claim 13 wherein the industrial process is selected from the group consisting of raw water processes, waste water processes, industrial water processes, municipal water treatment, food and beverage processes, pharmaceutical processes, electronic
10 manufacturing, utility operations, pulp and paper processes, mining and mineral processes, transportation-related processes, textile processes, plating and metal working processes, laundry and cleaning processes, leather and tanning processes, and paint processes.

16. The method of claim 13 wherein the feed stream contacts the reverse osmosis
15 membrane in a cross flow relative to the reverse osmosis membrane.

17. The method of claim 13 wherein the feed stream contacts the reverse osmosis membrane in a flow direction substantially perpendicular to the reverse osmosis membrane.

20 18. The method of claim 13 wherein the inert fluorescent tracer is selected from the group consisting of 3,6-acridinediamine, N,N,N',N'-tetramethyl-,monohydrochloride; 2-anthracenesulfonic acid sodium salt; 1,5-anthracenedisulfonic acid; 2,6-anthracenedisulfonic acid; 1,8-anthracenedisulfonic acid; anthra[9,1,2-cde]benzo[rst]pentaphene-5,10-diol, 16,17-

dimethoxy-,bis(hydrogen sulfate), disodium salt; bathophenanthrolinedisulfonic acid disodium salt; amino 2,5-benzene disulfonic acid; 2-(4-aminophenyl)-6-methylbenzothiazole; 1H-benz[de]isoquinoline-5-sulfonic acid, 6-amino-2,3-dihydro-2-(4-methylphenyl)-1,3-dioxo-, monosodium salt; phenoxazin-5-i um, 1-(aminocarbonyl)-7-(diethylamino)-3,4-dihydroxy-,
5 chloride; benzo[a]phenoxazin-7-i um, 5,9-diamino-,acetate; 4-dibenzofuransulfonic acid; 3-dibenzofuransulfonic acid; 1-ethylquinaldinium iodide; fluorescein; fluorescein, sodium salt; Keyfluor White ST; benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-[4-[bis(2-hydroxyethyl)amino]-6-[(4-sulfophenyl)amino]-1,3,5-triazin-2-yl]amino]-,tetrasodium salt; C.I. Fluorescent Brightener 230; benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-[4-[bis(2-hydroxyethyl)amino]-6-[(4-sulfophenyl)amino]-1,3,5-triazin-2-yl]amino]-,tetrasodium salt; 9,9'-biacridinium, 10,10'-dimethyl-, dinitrate; 1-deoxy-1-(3,4-dihydro-7,8-dimethyl-2,4-dioxobenzo[g]pteridin-10(2H)-yl)- ribitol; mono-, di-, or tri-sulfonated naphthalenes selected from the group consisting of 1,5-naphthalenedisulfonic acid, disodium salt (hydrate); 2-amino-1-naphthalenesulfonic acid; 5-amino-2-naphthalenesulfonic acid; 4-amino-3-hydroxy-1-naphthalenesulfonic acid; 6-amino-4-hydroxy-2-naphthalenesulfonic acid; 7-amino-1,3-naphthalenesulfonic acid, potassium salt; 4-amino-5-hydroxy-2,7-naphthalenedisulfonic acid; 5-dimethylamino-1-naphthalenesulfonic acid; 1-amino-4-naphthalene sulfonic acid; 1-amino-7-naphthalene sulfonic acid; and 2,6-naphthalenedicarboxylic acid, dipotassium salt; 3,4,9,10-perylenetetracarboxylic acid; C.I. Fluorescent Brightener 191; C.I. Fluorescent Brightener 200;
10 benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-(4-phenyl-2H-1,2,3-triazol-2-yl)-, dipotassium salt; benzenesulfonic acid, 5-(2H-naphtho[1,2-d]triazol-2-yl)-2-(2-phenylethenyl)-, sodium salt; 1,3,6,8-pyrenetetrasulfonic acid, tetrasodium salt; pyranine; quinoline; 3H-phenoxyazin-3-one, 7-hydroxy-, 10-oxide; xanthylum, 9-(2,4-dicarboxyphenyl)-3,6-bis(diethylamino)-, chloride,
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disodium salt; phenazinium, 3,7-diamino-2,8-dimethyl-5-phenyl-, chloride; C.I. Fluorescent Brightener 235; benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-[[4-[bis(2-hydroxyethyl)amino]-6-[(4-sulfophenyl)amino]-1,3,5-triazin-2-yl]amino]-, tetrasodium salt; benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-[[4-[(2-hydroxypropyl)amino]-6-(phenylamino)-1,3,5-triazin-2-yl]amino]-, disodium salt; xanthylium, 3,6-bis(diethylamino)-9-(2,4-disulfophenyl)-, inner salt, sodium salt; benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-[[4-[(aminomethyl)(2-hydroxyethyl)amino]-6-(phenylamino)-1,3,5-triazin-2-yl]amino]-, disodium salt; Tinopol DCS; benzenesulfonic acid, 2,2'-(1,1'-biphenyl)-4,4'-diyldi-2,1-ethenediyl)bis-, disodium salt; benzenesulfonic acid, 5-(2H-naphtho[1,2-d]triazol-2-yl)-2-(2-phenylethenyl)-, sodium salt; 7-benzothiazolesulfonic acid, 2,2'-(1-triazene-1,3-diyldi-4,1-phenylene)bis[6-methyl-, disodium salt; and all ammonium, potassium and sodium salts thereof; and all mixtures thereof.

19. The method of claim 13 wherein the inert tracer is measured in an amount ranging from about 5 ppt to about 1000 ppm.

20. A reverse osmosis membrane separation system capable of purifying an aqueous feed stream suitable for use in an industrial process comprising:
a semi-permeable reverse osmosis membrane capable of separating the aqueous feed stream containing an inert tracer into a permeate stream and a concentrate stream to remove one or more solutes from the aqueous feed stream;
a detection device capable of fluorometrically measuring an amount of the inert tracer ranging from about 5 ppt to about 1000 ppm in at least one of the aqueous feed stream, the

permeate stream and the concentrate stream wherein the detection device is capable of producing a signal indicative of the amount of inert tracer that is measured; and
a controller capable of processing the signal to monitor and/or control the purification of the aqueous feed stream.

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21. The reverse osmosis membrane separation system of claim 20 wherein the controller is capable of monitoring a normalized permeate flow based on the measurable amount of inert tracer.

10 22. The reverse osmosis membrane separation system of claim 20 wherein the controller is capable of monitoring a percent rejection of solutes based on the measurable amount of inert tracer.

15 23. The reverse osmosis membrane separation system of claim 20 wherein the controller is capable of monitoring leaks in the semi-permeable reverse osmosis membrane based on the measurable amount of inert tracer.

20 24. The method of claim 20 wherein the controller is capable of controllably and responsively adjusting one or more parameters specific to reverse osmosis membrane separation in order to enhance a performance of the reverse osmosis membrane separation system.

25. The method of claim 20 wherein the controller is capable of controllably adjusting a feed rate of a treatment agent added to the reverse osmosis membrane separation system.

26. A method of monitoring and controlling a reverse osmosis membrane separation process including a reverse osmosis membrane capable of removing solutes from a feed stream for use in an industrial process comprising the steps of:

- 5 adding an inert tracer to the feed stream;
- contacting the reverse osmosis membrane with the feed stream;
- separating the feed stream into a first effluent stream and a second effluent stream to remove solutes from the feed stream;
- providing a fluorometer to detect the fluorescent signal of the inert tracer in at least one of the feed stream, the first effluent stream and the second effluent stream;
- 10 using the fluorometer to measure an amount of the inert tracer ranging from about 5 ppt to about 1000 ppm in at least one of the feed stream, the first effluent stream and the second effluent stream; and
- evaluating one or more process parameters specific to the reverse osmosis
- 15 membrane separation process based on the measurable amount of the inert tracer.

27. The method of claim 26 wherein the process parameters are selected from the group consisting of operational parameters, chemical parameters, mechanical parameters, a percent recovery, a normalized permeate flow, a percent rejection, a differential pressure, a hydraulic holding time and combinations thereof.

28. The method of claim 26 wherein the inert tracer is measured in an amount ranging from about 1 ppb to about 50 ppm based on the amount of the inert tracer that is measured.

29. The method of claim 28 further comprising monitoring the reverse osmosis membrane separation process to detect leaks in the reverse osmosis membrane based on the amount of the inert tracer that is measured.

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30. The method of claim 28 comprising controlling an amount of scalants and/or foulants depositing on the reverse osmosis membrane.